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Theory and Application

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Abstract

This paper develops a theory of *efficient* design of financial securities when different parties in a corporate relationship contract under *multilateral* asymmetric information. A methodology for analyzing general financial contracting games is proposed. Rigorous, game-theoretic criteria such as incentive-constrained *ex ante*, *interim*, and *ex post* efficiency are used to evaluate the welfare properties of different security designs. The *threat points* of the various parties are shown to hold the key to overall contracting efficiency, and financial securities become relevant for efficiency only through the threat points.

In order to motivate the issue, an application involving security design in *joint-ventures* is presented first. The theory of efficient security design is presented next, in the context of a large class of general financial contracting games involving investments and multilateral asymmetric information. It is shown that, under weak conditions, *all* securities that are efficient from an *ex ante* and *interim* viewpoint involve a *quasi-debt* feature. Moreover, while a quasi-debt structure improves efficiency in firms with high capital intensity, it has no welfare advantage in firms with little physical capital. Importantly, the results are robust in the sense that they hold whether the agents are risk-neutral or risk-averse, under any distributional assumptions, and regardless of the exact extensive-form specification of the contracting game.

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INTRODUCTION

Financial contracts typically specify security allocations for the sharing of inputs and outputs among the various parties involved in the financial transactions, along with various clauses pertaining to the rights and responsibilities of the parties, and ultimately, the mechanism for the enforcement of the contracts as well. Much of the financial contracting and security design literature is concerned with analyzing these important features.[1] A relatively ignored, but equally important, issue in many financial contracting relationships is that security allocations of contracting parties in one period may act as their *threat points* for contracting in future periods. In particular, if some or all the contracting parties are to receive large security allocations in one period, overall contracting efficiency may be affected. This is because higher payoffs in one period may increase the threat points of the contracting parties, and hence increase their ability to disagree in the next period. While this possibility may have no welfare implications when contracting under complete information or unilateral asymmetric information, it can be expected to have serious welfare effects under *multilateral* asymmetric information — since privately informed agents are more likely to disagree.[2] Hence, efficient design of securities under multilateral asymmetric information must involve non-trivial intertemporal tradeoffs between the security allocations of the various parties in one period, and those in future periods. To put it another way, efficient design of financial securities must involve *endogenous* choices of threat points, with a view to promoting overall contracting efficiency.

A related welfare issue centers on debt-like securities, which are among the most popular form of corporate securities. A *debt-like* or *quasi-debt* security can be defined as one that assigns all the assets to one party in certain "low" states of nature, and offers the other party (or parties)

[1]See Allen and Winton (1995) for an overview.
[2]The reason unilateral asymmetric information may not have welfare effects is that, in many cases where only one party is privately informed, full efficiency can be achieved by giving all the informational rents to the informed party. As we show here, such a solution may not be feasible when many parties are privately informed (multilateral asymmetric information).

a residual claim.[3] Such securities can be contrasted with the more general sharing rules, in which each party gets a non-zero share of the output in *every* state of nature.[4] While social norms can be expected to rule out negative wealth allocations in bad states, the interesting issue is why the all- or-nothing-in-bad-states allocations of debt-like securities are optimal.

Among the early explanations involved the costly state-verification model of Townsend (1979). As Townsend himself acknowledged, debt-like structures disappear if stochastic monitoring of cashflows is allowed. Considerable legal and economic costs, both direct and indirect, are often incurred to enforce debt-like contracts. Chief among them, the bankruptcy procedures under Chapter 11, are often complex, protracted and involve billions of dollars of assets. In light of these enormous costs, it is of interest to know whether such security structures are *efficient* in the first place, from a social welfare point of view. Despite the recent progress in understanding optimal design of securities, their welfare properties are far from well-understood. In particular, while existing works have shed valuable insights on the importance of debt-like securities in *specific* models from the viewpoints of certain claimants, it is not clear why they are so *pervasive* in a wide variety of contexts.

This paper shows that quasi-debt securities have special welfare properties that help achieve efficiency (according to various criteria) in a large class of general financial contracting games, when the various parties are privately informed and are involved in a multiperiod contracting relationship. A methodology for analyzing general financial contracting games is proposed. Efficient design of securities is modeled here, by explicitly taking into account the possibility that these securities may serve as threat points for further contracting. Three types of efficiency concepts, as proposed by Holmström and Myerson (1983), are considered. These three welfare notions vary depending on *when* the welfare of the contracting parties is computed. Accordingly, if the total welfare is computed before the parties find out their private informa-

[3]This is sometimes called a *priority* or *absolute priority* rule. Note that while the payoffs in the low states are well-specified, the payoffs in the high states are not. In particular, features such as fixed payment (standard debt), convertibility, and caps in the high states are possible within the broad category of quasi-debt. There are also other features of debt-like securities, such as state-contingent property rights, that have been studied in other contexts (see Hart and Moore (1988) and Zender (1991)), but are not the focus here.

[4]This is the only type of sharing rule allowed under certain strict religious traditions, for instance, the Jewish and Islamic law. In fact, such laws do not permit debt-like securities at all.

tion (on an unconditional expectations basis), then the *ex-ante* efficient contract maximizes total welfare, subject to incentive constraints. If the total welfare is computed when each contracting party knows only its own private information (on a conditional expectations basis), then we get *interim* efficient contracts. Finally, if the welfare is determined after all (private) information becomes common knowledge, then we get *ex-post* efficient contracts.

To illustrate the main ideas, efficient security design is presented first in simple a model of joint-ventures.[5] Two firms (or investors) make initial investments in a joint-venture that generates cashflows at the end of the first period. The firms then find out their private benefits from the project, and negotiate to determine whether the project should be continued at all. If an agreement is reached to continue the project, an additional investment is required, which must be shared between the joint-venture partners. On the other hand, if they cannot agree on the terms for continuation, the project is abandoned and the assets divided up between the partners as per the contract. The contract between the two venture partners specifies not only whether the project is to be continued, but also the security allocations and transfer payments for the joint-venture partners, even in the event of a disagreement.

It is first shown that, from an ex ante welfare viewpoint, security design is relevant only in the disagreement states, solely for the determination of the threat points. If disagreements are likely, then the *ex ante* efficient contract offers the firm that is more likely to *unilaterally* disagree a debt-like security, and offers the other, less disagreeable firm a residual claim. Such a security structure serves to mitigate the effect of threat points in achieving overall *ex ante* efficiency. Finally, the ex ante welfare of both firms can be improved by contracting through an intermediary (eg. a bank), if it is offered a standard debt security.

We then study an abstract and fairly general contracting relationship where two risk-neutral parties, after making initial investments, find out their private information, and negotiate to continue the relationship. A contract between the two must specify not only the actions and decisions for the contracting parties and sharing of inputs and outputs between them, but also their payoffs in the event of a disagreement, i.e., their threat points. In this framework, we characterize the necessary and sufficient conditions for the *ex-ante* and *interim* efficient designs to

[5]The model of joint-ventures presented in Section 1 is highly stylized, and is not meant to capture all the relevant features of joint-ventures. The main purpose of this model is to illustrate the theory of efficient security design that follows in Section 2.

involve debt-like securities. These conditions are rather weak in the following sense. They require only that i) disagreements be possible, and ii) that the contracting parties' be *asymmetrical*, in the sense that their subjective likelihoods of a unilateral disagreement be different, conditional on their private information.

It is shown that both the *ex-ante* and *interim* welfare of these two contracting parties can be strictly improved by negotiating through an uninformed intermediary, who will receive a standard debt security. This improvement comes not from the usual increased risk-sharing opportunities, but from a reduction in the threat points for the two informed agents, since all parties are risk-neutral here. Moreover, while a quasi-debt structure improves efficiency in firms with high capital intensity, it has no welfare advantage in firms with little physical capital. Finally, and more importantly, the results are robust in the sense that they hold whether the agents are risk-neutral or risk-averse, under any distributional assumptions, and regardless of the exact extensive-form specification of contracting games.

Related work on security design includes Allen and Gale (1988), who show that there may not exist any unique distribution of cashflows into the standard contingent claims under frictions. Madan and Soubra (1991) modify this model to include costs of marketing new financial products and show that more general contingent claims are possible. Aghion and Bolton (1992) use an incomplete contracting framework to argue that debt-like contracts may improve efficiency by allocating control rights to the debtholders in the event of bankruptcy. Hart and Moore (1988) examine state-contingent property rights associated with debt and equity. In a similar vein, Zender (1991) views bankruptcy as an efficient transfer of control of a firm to the debtholders. Hart and Holmström (1987) are interested in solving agency problems with optimal contracts. Nachman and Noe (1993) use signalling motives for optimal design of securities. Townsend (1979) and Diamond (1984) focus on constant payment schemes similar to debt, as a way of solving incentive problems under certain conditions. Williams (1987) also argues that debt and equity may be optimal from an incentive point of view. Winton (1993) develops a theory of limited liability, based on the monitoring activities of outside investors, and the unobservability of their wealth. Boot and Thakor (1994) argue that information sensitivity may be an important consideration in security design. In a similar vein, Glaeser and Kallal (1997) argue that issuers may sometimes restrict information to prevent exacerbation of asymmetric information problems. Demange and Laroque (1995) examine the trade-offs faced by an entrepreneur between insurance opportunities and insider informational advantage in security design. In contrast, Rahi (1993) finds that equity is optimal for an entrepreneur. Duffie and Jackson (1989) study futures contract design in a transaction cost model. DeMarzo and Duffie (1995) analyze a liquidity based model of security design. Duffie and Rahi (1995) offer a good survey of financial innovations and security design, mostly under incomplete markets. Dewatripont and Tirole (1994) and Repullo and Suarez (1995) propose models in which investors holding different claims have better monitoring incentives. Finally, in joint ventures, Darrough and Stoughton (1989) examine the issue of profit-sharing in a bargaining framework, but are not interested in efficient threat point design.[6]

This paper differs from the above literature in six aspects. First, while these works offer rich insights, none of them explicitly and dynamically links the security design problem to the design of agents' threat points, as is done here. Second, debt-like securities in this paper are efficient solutions to a wide variety of financial contracting games, and are not limited to specific capital structure or corporate control issues modeled in the above papers. Third, we provide a more comprehensive and game-theoretically rigorous welfare treatment of security design than the existing literature. Fourth, we characterize efficient securities without assuming any cooperative bargaining solutions, such as the Nash bargaining solution or Shapley value. Fifth, we analyze the more difficult case of *multilateral* asymmetric information, which has not been attempted in the literature. Finally, we propose a methodology for analyzing general contracting games that can be used in other applications as well.

The paper is organized as follows. In Section 1 presents the joint-venture application while Section 2 presents the general theory of efficient security design. Section 3 concludes with a discussion of the robustness of the results. All the proofs can be found in Appendix.

1. APPLICATION: JOINT-VENTURE & SECURITY DESIGN

Consider the case of two firms (or entrepreneurs) entering into a joint venture, which

[6]In addition, Maskin and Tirole (1992) recognize the importance of the status quo contract, but do not consider threat point design. In the bargaining literature, threat points are commonly assumed to be exogenous. An exception is the Stähl-Rubinstein solution (Rubinstein 1982) which also treats offers in one period as threat points for future periods as we do here, but not under asymmetric information. Rubinstein (1988) examines dynamic bargaining under incomplete information, but is not interested in security design.

requires a total capital investment c, to be made in two stages. In the first stage, each firm $i(i = \{1,2\})$ makes an *initial* investment of $I_i \geq 0$ in the new venture. Let $I = I_1 + I_2$. This investment produces random cashflows $\tilde{y}_1$ at the end of the first period.[7]

The joint venture partners then receive private information, and decide whether to proceed with the project at all. If a decision is taken to continue the project, the first period cashflow y_1 is reinvested, and in addition, the project will require a second round of financing to the tune of $c - I - y_1$. The joint venture will ultimately produce common cashflows $\tilde{y}_2$ which will be shared between the two venture partners. In addition, each firm i will also gain *private* benefits worth b_i from the project that can not be shared with the other firm.[8] If, on the other hand, the two firms can not come to an agreement, then the joint-venture is liquidated and the assets distributed back to the partners at the end of the first period.

The exact sequence of events is as follows.

t = 0: Each firm i makes an initial investment I_i.

t = 1: Cashflows $\tilde{y}_1$ realized. Each firm then finds out its private benefits b_i that it will receive if the joint venture goes ahead.

t = 2: Both firms play a bargaining game Γ that determines whether the project will be continued, as well as their individual security and payoff allocations from the joint-venture. If the joint-venture is approved, then the project requires an additional investment of $c - I - y_1$, which must be shared between the two firms.

t = 3: If an agreement is reached to continue the project, the two joint-venture partners contribute their share of additional funding as specified by the contract. The project will yield, eventually, common cashflows $\tilde{y}_2$ and private benefit b_i for the two firms. If the project is discontinued, the assets are liquidated for $I + y_1$, and paid back to the firms according to their contract.

We assume that the private benefits b_i are private information, but it is common knowl-

[7]The two-stage financing structure is intended to capture the incentive effects arising from the initial investment in the second stage.

[8]These private benefits may arise from (unmodeled) synergies generated by the joint-venture with the parent firms' existing operations. For example, an airline reservation system joint venture between two airlines may generate (possibly different) additional operating income for each of those airlines separately. Or, a marketing joint venture between two auto companies may generate synergies specific to each parent company that can not be shared.

edge that they are distributed independently with cumulative probability $G_i(\cdot)$ and positive density $g_i(\cdot)$ over an interval $[\underline{b}_i, \bar{b}_i]$. Furthermore, $b_i - \frac{[1 - G_i(b_i)]}{g_i(b_i)}$ is assumed to be non-decreasing in b_i.[9] As will become clear, the assumption that the benefits b_i are private information is important, since it offers the firms opportunities to extract rents from continuing the joint-venture. In turn, the possibility of rent extraction may adversely affect overall efficiency, in a sense to be made precise later. In contrast, it is well-known that common cashflows *per se* do not give rise to serious incentive problems [see Grossman and Hart (1988) and Harris and Raviv (1988)].[10] Hence, in the interest of focus, we will assume that both $\tilde{y}_1$ and y_2 are common knowledge and $\tilde{y}_1$ is distributed according to the cumulative distribution $G_y(\cdot)$ over $[\underline{y}, \bar{y}]$, while y_2 is simply deterministic.[11] For non-triviality, assume that it is not optimal for only one firm to continue the joint-venture unilaterally, i.e., $c - \bar{y} - I_1 > y_2 + \max\{\bar{b}_1, \bar{b}_2\}$. Throughout, the expectation operators $E(\cdot)$ (over b_1 and b_2) and $E_{-i}(\cdot)$ (conditional on b_i) will be used extensively. We assume no discounting.

The bargaining game Γ between the firms could be fairly general, and can involve complex sequence of moves, including many rounds of detailed offers and counter-offers from each firm regarding the terms for the continuation of the project. Such dynamic, extensive form games can be quite difficult to analyze in general. Fortunately, in the absence of message space restrictions,[12] we can apply the Revelation Principle (Myerson 1979), and can consider without loss of generality, only static *direct revelation* games Γ^* where each firm reports its private information confidentially to some disinterested coordinator.[13] The coordinator then makes the final allocations according to the agreed-to contract, as functions of the reports made to her. In essence, the Revelation Principle ensures that any Bayesian Nash equilibrium contract of the extensive form game Γ can be effectively duplicated by an equivalent Bayesian Nash equilibrium

[9] This is the standard hazard-rate condition that is satisfied by many commonly encountered (log-concave) distributions, including uniform and normal.

[10] This is because, since the common cashflows are shareable, it is in the interest of each firm to agree to the first-best, efficient solution.

[11] To make the problem interesting, a parameter restriction is subsequently imposed on $\bar{y}$, which will be made precise in Proposition 1.3.

[12] These are restrictions on the messages that the two firms can communicate with in the contracting game. For more on message space restrictions, see Reichelstein and Reiter (1988).

[13] This coordinator is not a claimholder, and has no economic role in the model. In fact, the coordinating function can also be performed by a machine.

contract of the direct revelation game Γ^* — by carefully incorporating appropriate incentives for the two firms. The analytical advantage of the direct revelation game is that it is a simpler, static game of uniform dimension in strategy space, in contrast to the actual extensive form game which may be dynamic and of varying dimensions.

A contract κ between the joint-venture partners specifies i) the decision whether to proceed with the project, ii) their share of the new investment, and most importantly iii) the allocation of financial securities and monetary transfers between the two — all as functions of their informational reports.[14] As mentioned, if the partners can not agree to continue the project, then the joint-venture is liquidated for $I + y_1$, and the proceeds distributed to the two firms as per the security structure specified in the contract κ. Thus, the contract κ specifies the payoffs received by the two firms not only in the event of an agreement, but also in the event of a disagreement. In the parlance of game theory, it can be said to incorporate *endogenously* the *threat points* of the two firms in the bargaining game. This is an important feature that distinguishes the contracting game here from many of the financial contracting games analyzed in the literature. As will be seen later, the possibility of such a disagreement gives rise to the key results in this paper. In particular, careful design of securities in contract κ can weaken the threat points of the firms and improve efficiency.

The starting point of our analysis is the incentives of the joint-venture partners in the bargaining game. Formally, applying the Revelation Principle, we only need to consider without loss of generality, *direct revelation* contracts of the form $\kappa(b) \equiv \; < p, s, x > (b)$ where

- $p(b_i, b_j)$ is the probability of continuation of the joint venture,
- $s_i(b_i, b_j)$ is the security allocated to firm i, and
- $x_i(b_i, b_j)$ is the expected payment made by firm i.[15]

A disagreement in the contracting game occurs if $p(b_i, b_j) = 0$. The main focus of the contract here will be on the role of securities $s_i(\cdot, \cdot)$ in endogenously determining the threat

[14]The sharing of the initial investment can also be made part of the contract, but this is left out of the formal definition for the ease of exposition. The firms know the structure of the contract as stated (i.e., the decision rules) before they make any decisions.

[15]Strictly speaking, of course, the contract is also a function of the cashflows y_i, but for ease of exposition, only the reduced-form notation will be used here.

points for the contracting game.[16] Ex post settlement implies that

$$\sum_{i=1}^{2} x_i(b_i, b_j) \quad = \quad cp(b_i, b_j) - I - y_1.$$

That is, if $p(b_i, b_j) = 1$, the firms together must invest an additional $c - I - y_1$. If $p(b_i, b_j) = 0$, then they should get back a total of $I + y_1$. The conditional expected payoffs to firm i, given that the initial investment has already been made, can be written as

$$\Pi_i[\hat{b}_i|b_i] = E_{-i}\{[y_2 s_i(\hat{b}_i, b_j) + b_i]p(\hat{b}_i, b_j)\} - E_{-i}\{x_i(\hat{b}_i, b_j)\}, \tag{1.1}$$

for all i s.t. $b_i, \hat{b}_i \in [\underline{b}_i, \bar{b}_i]$, where b_i is the true private benefit and $\hat{b}_i$ is the reported one. For analytical convenience, define

$$\begin{aligned} P_i(\hat{b}_i) &= E_{-i}\{p(\hat{b}_i, b_j)\} \\ S_i(\hat{b}_i) &= E_{-i}\{s_i(\hat{b}_i, b_j)p(\hat{b}_i, b_j)\} \quad \text{and} \\ X_i(\hat{b}_i) &= E_{-i}\{x_i(\hat{b}_i, b_j)\}. \end{aligned} \tag{1.2}$$

Here, $P_i(\hat{b}_i)$ can be interpreted as the expected probability of the project going forward, $S_i(\hat{b}_i)$ as the expected share allocation of firm i, and $X_i(\hat{b}_i)$ the expected payment to be made by firm i — all as functions of its report $\hat{b}_i$. Equation (1.1) then becomes

$$\Pi_i[b_i|\hat{b}_i] = \quad y_2 S_i(\hat{b}_i) + b_i P_i(\hat{b}_i) - X_i(\hat{b}_i), \quad \forall i \quad \text{and} \quad b_i, \hat{b}_i \in [\underline{b}_i, \bar{b}_i]. \tag{1.3}$$

The contract κ should offer sufficient incentives for the joint venture partners a) to report their private benefits truthfully (*incentive compatibility*), and b) to participate in the contracting game voluntarily (*individual rationality*) to be in Bayesian Nash equilibrium. Define $\Pi(b_i) = \Pi[b_i|b_i]$ as the expected payoff to i from telling the truth, conditional on her private benefit b_i. Then, incentive compatibility (IC) implies

$$\Pi_i(b_i) \quad \geq \quad y_2 S_i(\hat{b}_i) + b_i P_i(\hat{b}_i) - X_i(\hat{b}_i) \quad \forall i \quad \text{and} \quad b_i, \hat{b}_i \in [\underline{b}_i, \bar{b}_i]. \tag{1.4}$$

[16]Since each agent contributes I_i of capital, it may seem natural that $s_i(\cdot,\cdot) = \dfrac{I_i}{I_1 + I_2}$. However, such a contract may not be efficient overall, as will be shown in this paper.

The IC condition (1.4) says that the conditional expected payoffs from truthtelling weakly dominate those from lying. The following lemma characterizes the IC contract.

LEMMA 1.1. *A contract κ is incentive compatible iff $\Pi_i(b_i)$ is non- decreasing and convex, and $\Pi_i'(\cdot) = P_i(\cdot)$, a.e. Furthermore,*

$$\Pi_i(b_i) \quad = \quad \Pi_i(b_i^*) + E\left\{\frac{P_i(\hat{b}_i)}{g_i(\hat{b}_i)} 1_{\{b_i^* \leq \hat{b}_i \leq b_i\}}\right\} \quad \forall b_i \in [\underline{b}_i, \bar{b}_i], \tag{1.5}$$

where $b_i^* \in [\underline{b}_i, \bar{b}_i]$ represents the benefit level at which firm i's conditional expected payoff from continuing the project is the lowest.

Intuitively, the joint venture partners have an incentive to under-report their private benefits, lest they be asked to shoulder a greater share of the additional investment. This gives rise to the possibility of (informational) rent-extraction by the two venture partners. The IC contract must therefore offer "bribes" to the firms, in order to get them to report truthfully. This explains why the IC contract rewards higher benefit reports with (weakly) higher payoffs for the firms, at a (weakly) increasing rate. Bribes for reporting the truth can be costly, however, and may not always be feasible. This raises the possibility that the outcome of the contracting game may not always be *efficient*, in the sense that agreements that should have been reached in the absence of private information can no longer be guaranteed.[17]

In order to induce the two firms to participate voluntarily in the contracting game, they must also be guaranteed non-negative payoffs. The individual rationality constraints (IR) are thus given by

$$\Pi_i(b_i) \quad \geq \quad 0, \quad \forall i \quad \text{and} \quad b_i \in [\underline{b}_i, \bar{b}_i] \tag{1.6}$$

The status quo payoff of the firms can be greater than zero, however. This is because, if there is no agreement in the contracting game, the joint-venture is dissolved, the assets are liquidated for $I+y_1$ and paid back to the venture partners — as per their security claims $s_i(\cdot,\cdot)$. The possibility of this *ex post* settlement will, naturally, affect the incentives of the firms to participate in the contracting game. An important case of disagreement arises when a firm's benefit is so low that the project is certain to be aborted — even if the other firm's benefit turns out to be the

[17] More precise definitions of efficiency will be offered shortly.

highest possible, i.e., $\bar{b}_j$. We call this the *unilateral* disagreement. The ability to cause unilateral disagreement gives the firms bargaining power, and determines their threat points.

The possibility that the venture partners may receive a portion of the liquidation value in the event of a unilateral disagreement implies that the individual rationality constraints in (1.6) will not be binding. In order to specify the *binding* individual rationality constraints (BIR), the threat points, i.e., the liquidation payoffs of the firms in the unilateral disagreement states, must be specified first. To this end, let $b_i^*(\kappa)$ and $b_j^*(\kappa)$ respectively be the types of firms i and j that can cause a unilateral disagreement. That is, the contracting game ends in disagreement if either $b_i \leq b_i^*(\kappa)$ or if $b_j \leq b_j^*(\kappa)$.[18] For $b_i \leq b_i^*(\kappa)$, there are two cases to consider:

i) $b_i \leq b_i^*(\kappa)$ and $b_j \geq b_j^*(\kappa)$. Here firm i is a "bad" type and firm j is a "good" type. This case is not a problem, as firm i can be penalized completely, with all the liquidation value going to firm j.[19]

ii) $b_i \leq b_i^*(\kappa)$ and $b_j \leq b_j^*(\kappa)$. Here both firms are "bad" types and hence it is not clear which firm should be penalized. Since the ex post settlement constraint is binding, each firm must receive a portion of the liquidation payoffs, to be specified by its security allocation $s_i(b_1, b_2)$. Firm i receives its share of the liquidation value, if and only if firm j's benefit b_j turns out to be less than $b_j^*(\kappa)$ — the probability of it being $G_j[b_j^*(\kappa)]$.

Furthermore, if firm i has a true benefit less than the critical value b_i^*, it can be induced to report the truth only if the security allocation $s_i(b_1, b_2)$ is such that it offers a *constant* share of the liquidation payoff throughout the unilateral disagreement region, i.e., for all $b_i \leq b_i^*$. If not, the firm will lie and report the type that will yield the highest payoff within the unilateral disagreement region. It follows from the monotonicity property of IC contracts (Lemma 1.1), that this reported type will be b_i^*.

Let the constant share of the liquidation payoff for firm i be $\bar{s}_i$, s.t. $\bar{s}_1 + \bar{s}_2 = 1$. Formally,

$$s_i(b_1, b_2) \quad = \quad \bar{s}_i, \quad \text{iff} \quad b_i \leq b_i^*(\kappa) \quad \& \quad b_j \leq b_j^*(\kappa). \tag{1.7}$$

[18]The existence of a unilateral disagreement set will be confirmed shortly.

[19]Such a transfer payment has the potential to affect firm j's incentive compatibility, but does not here because it is constant.

We are now ready to write the binding individual rationality (BIR) constraints:

$$\Pi_i[b_i] \quad \geq \quad \bar{s}_i(I+y_1)G_j[b_j^*(\kappa)] \quad \forall i, b_i \in [\underline{b}_i, \bar{b}_i].$$

Since from Lemma 1.1, $\Pi_i[b_i]$ is monotone, and since $b_i^*(\kappa)$ represents the type with the lowest expected payoff, the uncountably many BIR constraints can be simplified as

$$\Pi_i[b_i^*(\kappa)] \quad \geq \quad \bar{s}_i(I+y_1)G_j[b_j^*(\kappa)] \quad \text{for i = 1, 2.} \tag{1.8}$$

Note that the *threat points*, i.e., the expected payoffs (conditional on b_i) in the case of a unilateral disagreement, $\bar{s}_i(I+y_1)G_j[b_j^*(\kappa)]$, can be different for the two firms. Define $\mathcal{K}^*$ as the set of IC and BIR contracts. The following lemma characterizes the set $\mathcal{K}^*$.

LEMMA 1.2. *A contract $\kappa \in \mathcal{K}^*$, iff $P_i(b_i)$ is non-decreasing and*

$$E\left\{\left[y_2 - c + \sum_{i=1}^{2} b_i - \frac{[1-G_i(b_i)]}{g_i(b_i)}\right]p(b_i,b_j)\right\} + I + y_1 \quad \geq \quad \sum_{i=1}^{2} \bar{s}_i(I+y_1)G_j[b_j^*(\kappa)]. \tag{1.9}$$

The interpretation of inequality (1.9) is as follows. The first two terms represent the benefits from continuing the project. The next term, $[1-G_i(b_i)]/g_i(b_i)$, represents the informational rents paid to each firm. Lemma 1.2 says that for contract to be IC and BIR, the expected total benefits net of all costs — including informational costs — must be at least as great as the status quo expected payoff for the two firms. Note that, for IC and BIR contracts, the choice of the security $s_i(\cdot,\cdot)$ is relevant only in determining the threat points. Moreover, only the probability of continuance $p(b_i, b_j)$ is important for determining IC and BIR. In particular, the incentive payments $x_i(b_i, b_j)$ can be derived endogenously from $p_i(b_i, b_j)$.[20]

1.2. Efficient Securities

The equally weighted *ex-ante* welfare $W^E(\kappa)$ measures the ex ante expected gains from trade just before the two firms find out their private information, and can be written as

$$W^E[\kappa] \quad = \quad E\left\{[y_2 + b_1 + b_2 - c]p(b_i,b_j)\right\} + I + y_1. \tag{1.10}$$

[20] See equation (A5) in the Appendix.

The ex post efficient (or full-information or Pareto-optimal) contract κ_P^* is easily obtained by setting

$$p(b_i, b_j) = 1, \quad \text{iff} \quad y_2 + b_1 + b_2 \geq c$$

That is, the joint-venture is continued iff the total private and common benefits exceed the costs. The following proposition characterizes the parameter restrictions under which the ex post efficient contract is IC and BIR.

PROPOSITION 1.3. *The ex post efficient contract $\kappa_P^* \in \mathcal{K}^*$ for all $I + y_1 > I^*$, where*

$$\begin{aligned} I^* &= -E\left\{\left[y_2 - c + \sum_{i=1}^{2} b_i - \frac{[1 - G_i(b_i)]}{g_i(b_i)}\right] 1_{\{y_2+b_1+b_2>c\}}\right\} \quad \text{and} \\ 1_{\{y_2+b_1+b_2>c\}} &= 1 \quad \text{iff} \quad y_2 + b_1 + b_2 > c. \end{aligned}$$

According to this result, IC and BIR contracts can be ex post efficient so long as the interim value of the project at the end of the first period is sufficiently large relative to the gains from continuing the project. Essentially, a high interim value acts as a financial cushion to smooth out any disagreements, as the firms have a lot to lose. From the point of view of security design, however, *ex-post* efficient contracts are not interesting, since the choice of the security $s_i(\cdot,\cdot)$, especially the threat point, is *irrelevant* for welfare — as disagreements never take place in equilibrium.[21] Hence in what follows, we assume that $I + \bar{y} < I^*$.

Define the *ex-ante* efficient contract κ_E^* as

$$\textbf{P1:} \quad \kappa_E^* = \underset{\kappa}{\text{argmax}} \quad W^E[\kappa] \quad \text{in (1.10)}$$
$$s.t. \quad \text{Condition (1.9)}.$$

In both expression (1.10) and condition (1.9), the choice of the security $s_i(\cdot,\cdot)$ is irrelevant for welfare if the joint venture proceeds, since common cashflows do not lead to incentive problems. However, the security structure will, in general, have an effect on the payoffs in the event of a unilateral disagreement, as is evident from the right-hand side of the constraint in **P1**. Hence, the following result is immediate.

[21] Of course, if we consider refinements of Bayesian-Nash equilibrium, then off-the-equilibrium disagreements become important. It can then be shown that the threat points become important even in ex post efficient contracts. We limit our attention to the more conservative case here.

PROPOSITION 1.4. *Under the ex ante welfare criteria, security design is relevant only in the event of a unilateral disagreement.*

Thus, security design has an effect on ex ante efficiency, but only through the threat points. Given this, one may expect that efficient security design would involve evenly balancing the threat points of the two firms. After all, by not giving any bargaining advantage to any one firm, the logic goes, efficiency may be improved. This turns out not to be true, as the shown by the following proposition.[22]

PROPOSITION 1.5. *For $I^* > I + y_1 > 0$ and $c > 0$, the ex-ante efficient contract κ_E^* is given by*

$$\begin{aligned} \bar{s}_i^* &= 0, \quad \textit{iff} \quad G_i[b_i^*(\kappa)] < G_j[b_j^*(\kappa)] \quad \text{and} \\ p^*(b_i, b_j) &= 1, \quad \textit{iff} \quad \sum_{i=1}^{2} \beta_i^\alpha(b_i) \geq c - y_2 \\ \textit{with} \quad & \beta_i^\alpha(b_i) = b_i - \alpha \frac{[1 - G_i(b_i)]}{g_i(b_i)}, \end{aligned} \tag{1.11}$$

where α satisfies (1.9) as an equality, and $b_i^*(\kappa)$ is the highest possible type of firm i that can cause a unilateral disagreement, defined implicitly by $\beta_i^\alpha[b_i^*(\kappa)] = c - y_2 - \bar{b}_j$.

That is, the joint venture is allowed to proceed if the sum of the benefits exceed the total costs, where the total costs include not only the cost of financing c, but also the informational costs $\alpha \sum_{i=1}^{2} E\{[1 - G_i(b_i)]/g_i(b_i)\}$. Note that α is a(n inverse) measure of the likelihood of disagreement, with $\alpha = 0$ representing no disagreement as in the case of the ex post contract seen earlier. Unilateral disagreement occurs if either firm can unilaterally preclude an agreement, i.e., $b_i \leq b_i^*(\kappa)$. The firm which receives no liquidation value in unilateral disagreement is the one whose expected probability of a unilateral disagreement $G_j(b_j^*)$, conditional on its valuation $b_i \leq b_i^*(\kappa)$, is the greater of the two in equilibrium. This represents the socially optimal choice of disagreement payoffs, given that these payoffs must add up to the liquidation value $I + y_1$.

[22] For expositional purposes, we have limited our attention in this section to *ex-ante* efficient contracts, although as will be shown in the next section, the general insights apply to *interim* efficient contracts as well.

The main reason why evenly balancing out the threat points is not efficient, is that the firms may differ in their ability to credibly and unilaterally disagree in equilibrium. Surprisingly, moreover, the firm with the greater threat point is *not* the *more disagreeable* one, i.e., the one which is more likely to unilaterally disagree in equilibrium. This is because, the more disagreeable firm's ex post settlement depends on the likelihood of the other firm being in the disagreement region, which will be the smaller of the two. Consequently, the firm which is more likely to disagree actually has a *lower* threat point, and ends up receiving all the wealth in the disagreement region under the ex ante efficient contract. Essentially, the asymmetry in the threat points of the two firms allows the firm with the greater of the threat points to be penalized, improving efficiency. Of course, this is more subtle than it appears, since the degree of disagreeability is determined endogenously in equilibrium by the design of the ex ante efficient security.

The firm which receives nothing in the disagreement region can be interpreted to have a *residual* claim in the joint venture. The other firm which receives all the wealth in the disagreement region has a claim that resembles *debt* in the low states, but in higher states the security can have a more general feature. In particular, if we introduce more structure into the problem (eg. moral hazard), features such as convertibility in the higher states (à la Green (1984)) can be generated as part of the efficient contract.

Finally, note that if the two firms are symmetrical in their threat points, i.e., $G_1(b_1^*) = G_2(b_2^*)$, then the right-hand side of (1.9) becomes $IG_i(b_i^*)$. Hence, the choice of the security $\bar{s}_i^*$, is irrelevant, even in the event of a disagreement. Basically, since both firms are equally disagreeable, there is no simple way to penalize one over the other, and this limits the overall ex ante efficiency.

1.3 Joint-Venture with an Intermediary

Whether the joint-venture partners have symmetrical or asymmetrical threat points, their ex ante welfare can be *strictly* improved, if they can contract through an intermediary such as a bank. This intermediary makes an initial investment $I_3 (I \geq I_3 \geq 0)$ in the project, but has no productive role, nor does it have any private information. It functions merely as a passive investor, and can be offered the following pure *debt* contract:

$$\pi_3(\hat{\kappa}(b), b) = \begin{cases} I + y_1 & \text{if} \quad b_i < b_i^*(\kappa) \quad \forall i \in \{1,2\} \\ D & \text{else,} \end{cases} \tag{1.12}$$

where D is a constant chosen so that the intermediary breaks even:[23]

$$I_3 \quad = \quad (I + y_1) G_1(b_1^*) G_2(b_2^*) + D[1 - G_1(b_1^*) G_2(b_2^*)]. \tag{1.13}$$

In the event the joint venture is discontinued the intermediary receives all the assets, and neither firm receives anything — driving their threat points down to zero. Hence, the binding individual rationality (BIR) conditions become

$$\Pi_i[b_i^*] \quad \geq \quad 0 \quad \forall i \quad \text{and} \quad b_i^* \in [\underline{b}_i, \bar{b}_i].$$

This constraint is more relaxed as compared to (1.9), and hence the ex ante welfare when the firms contract through an intermediary is greater than that in the previous case when they entered into the joint venture by themselves. Note that while the intermediary's security allocation in the disagreement state is unique, its allocation in the project continuance state D is not. As before, more complex security structures (eg. convertible options) can be derived by introducing further structure into the model, for example, moral hazard between the venture partners and the intermediary.

1.4. Example

Let b_1 be distributed uniformly over $[0, 1]$, and let b_2 be distributed independently of b_1 and uniformly over $[0, \bar{b}]$, where $\bar{b} < 1$. Assume $y_i = 0$ for simplicity. Under the full-information, ex post efficient contract, the joint-venture is continued iff $b_1 + b_2 > c$.

Under bilateral asymmetric information, the ex ante efficient contract involves the probability of the joint-venture going ahead:

$$p(b_1, b_2) \quad = \quad 1 \quad \text{iff} \quad b_1 + b_2 > c^*,$$

[23]Left unspecified in this contract, but understood, is the adjusted contract for the two joint-venture partners. Their initial investment is now reduced to $(I - I_3)$, and their final period cashflows are reduced by D.

where $c^* = (c + 2\alpha)/(1 + \alpha)$. Moreover, α is the solution to the equation

$$2\int_{c^*-1}^{1}\int_{c^*-b_1}^{\bar{b}}\{b_1 + b_2 - 0.5c - 1\}db_2db_1 \quad = \quad I\bar{s}_1b_2^* + I\bar{s}_2b_1^* - I.$$

The types of the two firms that disagree unilaterally are given by

$$b_1^* \quad = \quad c^* - \bar{b} \qquad \text{and} \qquad b_2^* \quad = \quad c^* - 1.$$

Clearly, $b_1^* > b_2^*$, and hence firm 1 is more likely to disagree than firm 2. Hence, the ex ante efficient contract sets $\bar{s}_1^* = 1$ and $\bar{s}_2^* = 0$.

An intermediary can strictly improve the ex ante welfare with the following contract

$$\pi_3(\hat{\kappa}(b), b) = \begin{cases} I & \text{if} \quad b_i < b_i^*(\kappa) \quad \forall i \in \{1, 2\} \\ D & \text{else,} \end{cases}$$

where D satisfies $I_3 = I(c^* - \bar{b})(c^* - 1) + D[1 - (c^* - \bar{b})(c^* - 1)]$. ∎

The following section presents the theory of efficient security design for a general class of financial contracting games.

2. EFFICIENT SECURITY DESIGN: THE THEORY

2.1 The Setup

Consider two *risk-neutral* agents 1 and 2, who invest I_i each at $t = 0$.[24] Let $I = I_1 + I_2$. As before, this investment is to be interpreted not as sunk, but rather as capital raised which can be used later to improve contracting efficiency. At $t = 1$, they find out their private information v_i. At $t = 2$, the agents play a bargaining game which determines the actions or decisions that the agents must take as well as the resulting payoffs. At $t = 3$, these decisions are taken, and the payoffs are realized.

A contract κ specifies not only the payoffs to each agent, but also the decisions or actions that the agents must follow for the rest of the game. In particular, the contract should also

[24] All the results can be shown to be valid for risk-aversion as well, due to the added insurance motive. We use risk-neutrality here, in order to emphasize the fact that our results arise from informational effects, and not from risk-sharing motives. See Section 3 for a discussion of the risk-aversion case.

specify the agents' utilities in case of a disagreement. We will be interested in contracts that are efficient at each stage of the game, in a sense to be made precise later. The class of contracting games studied in this section will be fairly general and abstract.

Although v_i is known only to i, it is common knowledge that v_i is distributed independently of v_j as $g_i(v)$ over V_i, which represents a finite set of private information. The standard hazard rate condition will be assumed: $v_i - \frac{[1 - G_i(v_i)]}{g_i(v_i)}$ is non-decreasing in v_i. Suppressing the probabilities, we directly define $E(\cdot)$ and $E_{-i}(\cdot)$ as the unconditional and conditional (on v_i) expectation operators respectively.

The contracting game between the agents Γ can be any general extensive form game, involving many rounds of complicated offers and counter-offers from both agents and can be fairly complex. As in the joint-venture application, in the absence of message space restrictions, we can apply the well-known Revelation Principle (Myerson 1979), and can consider without loss of generality, only *direct revelation* games Γ^* where the agents report their private information confidentially to a coordinator — who designs the contract for the agents. This coordinator has no economic role in the model. The Revelation Principle ensures that any equilibrium contract of a general contracting game Γ can be effectively duplicated by an equilibrium contract of the direct revelation game Γ^*.

Let a contract in the direct revelation game be $\kappa(v) \in \mathcal{K}$, where $\mathcal{K}$ is a compact set of all contracts. Typically, the contract will be of the form $\kappa(v) \equiv\ < \delta, s, x > (v)$ where $\delta(\cdot)$ is a *decision* to be taken at $t = 3$, $s(\cdot) \equiv \{s_1(\cdot), s_2(\cdot)\} \in \Delta$ is a *security allocation*, and $x_i(\cdot)$ is the expected *transfer payment* to agent i. The decision $\delta(\cdot)$ in general could be a vector, representing individual and/or joint decisions or actions to be taken by the agents, and can be interpreted broadly in many ways, depending on specific applications. For instance, in an application involving capital structure, the decision $\delta(\cdot)$ can be the amount of (additional) debt or equity to be issued. In the joint venture application presented in Section 1, the decision variable $\delta(\cdot) = p(b_i, b_j)$ the probability of continuance of the joint venture. In a managerial agency setting, $\delta_i(\cdot)$ could be the action taken by the manager. Finally, in a trading exchange with membership fees, $\delta(\cdot)$ may represent the volume of securities traded, and so on. The decision $\delta(\cdot)$ will usually result in some investment being made and output being produced or trading gains being generated — which must be shared between the agents according to the contract κ. In this section, however, there will be no need to specify the payoffs from a contract explicitly, since we define the agents' preferences directly over an abstract space of contracts. We assume no discounting.

If a disagreement occurs, however, then no decision is taken, and we follow the convention that $\delta(\cdot) = 0$. The contractual relationship is then dissolved, the initial investment liquidated for L and the agents are paid their share as per the contract.[25] Thus, the security allocation $s_i(\cdot, \cdot)$ also serves as a *threat point* for the contracting game, which will be the focus in this section. As will shortly be seen, it is this possibility of a disagreement that makes the contracting problem non-trivial, and gives rise to the main results.

The expected payoffs to the risk-neutral agents, induced by preferences over contracts, are given by $\pi_i(\cdot, v) : \mathcal{K} \mapsto \mathcal{R}$, which is assumed to be common knowledge.[26] Risk-neutrality implies that $\pi_i(\kappa(v), v)$ is linear in κ. For the agents' strategies in the direct contracting game Γ^* to be a Bayesian-Nash equilibrium, the contract κ must satisfy incentive compatibility (truth-telling) constraints in equilibrium:

$$E_{-i}[\pi_i(\kappa(v), v)] \quad \geq \quad E_{-i}[\pi_i(\kappa(v_j, \hat{v}_i), v)], \quad \forall v \in V, \quad \hat{v}_i \in V_i \quad \text{and} \quad i, j \in \{1, 2\}. \tag{2.1}$$

In order to ensure that the agents participate in the contracting negotiations at $t = 2$, they must get non-negative payoffs. Thus, the following individual rationality constraint must be satisfied:

$$E_{-i}[\pi_i(\kappa(v), v)] \quad \geq \quad 0.$$

The agents may receive more than zero in the case of a disagreement, however, since the possibility of disagreement may give rise to dissolution of the contract, which may affect the agent's payoffs. To take this into account, first define

$$\begin{aligned} V_i^*(\kappa) &\equiv \{v_i | \delta_i(v_i, \hat{v}_j) = 0 \quad \forall \hat{v}_j \in V_j, \} \quad \subset \quad V_i, \quad \forall i \quad \text{and} \\ V^*(\kappa) &\equiv V_1^*(\kappa) \times V_2^*(\kappa) \end{aligned} \tag{2.2}$$

[25] If there are first-period returns, as in the joint venture application of the last section, then $L > I$. If liquidation is costly, $L < I$. This is equivalent to "burning" or a partial free-disposal assets. See Section 3.

[26] More generally, the preferences can be defined over probability mixtures of pure contracts (see Section 3). This makes no difference here because of risk-neutrality.

That is, $V_i^*(\kappa)$ is the common knowledge set of "bad" valuations for agent i that leads to *unilateral* disagreements — i.e., irrespective of the other agent's report. In this event, since the contractual relationship is dissolved and the agents are paid off, the following *ex-post settlement* constraint must be satisfied:

$$\sum_{i=1}^{2} \pi_i(\kappa(v), v) \quad = \quad L, \quad \forall v \in V^*(\kappa). \tag{2.3}$$

This constraint implies that the agents are assured of a portion of the liquidation value, in the event of a unilateral disagreement. Hence, another set of constraints, called the *binding* individual rationality constraints (BIR), must also be satisfied:

$$E_{-i}[\pi_i(\kappa(v), v)] \quad \geq \quad \sup_{\{v_i \in V_i^*(\kappa)\}} E_{-i}[\pi_i(\kappa(v), v) 1_{\{v \in V^*(\kappa)\}}], \quad \forall v \in V \quad \text{and} \quad i = \{1, 2\}, \tag{2.4}$$

where $1_{\{v \in V^*(\kappa)\}} = 1$ if $v \in V^*(\kappa)$ and zero otherwise. In other words, the contract should guarantee the agents what they can get in case of a unilateral disagreement in the contracting game. The supremum in the R.H.S. of (2.4) takes into account the possibility that agent i's status quo utility may depend on her type, and hence she may lie and report a value that gives her the highest possible expected utility in the event of a unilateral disagreement. The hazard-rate assumption ensures that the highest type within $V_i^*(\kappa)$ determines the status quo utility.

Three remarks are in order. First, since the status quo utility in (2.4) depends endogenously on the choice of contract κ, careful contract selection can weaken the constraint. Second, only *unilateral* disagreements caused by reports $v \in V^*(\kappa)$ are relevant for BIR, although other reports may cause disagreements as well. For instance, disagreements caused by only one agent making "worse" reports relative to what is "expected" do not affect BIR constraints, since this agent can be penalized and the other, "better" reporting agent can be favored in the *ex-post* settlement. The problem arises when both agents are equally at fault for making "bad" reports, i.e., $v \in V^*(\kappa)$, since there is no obvious way to penalize one over the other. Such unilateral disagreements will affect the status quo utility in constraint (2.4), and can be binding. Finally, the status quo utility in (2.4) depends on both the liquidation value of the investment L, as well as the probability of disagreement.

Define the set of incentive compatible (IC) and binding individual rationality (BIR) contracts as $\mathcal{K}^*$. That is,[27]

$$\mathcal{K}^* \equiv \{\kappa | \kappa \in \mathcal{K} \quad \text{satisfies} \quad (2.1) \quad \text{and} \quad (2.4)\}. \tag{2.5}$$

LEMMA 2.1. *$\mathcal{K}^*$ is a closed, convex, and in general, proper subset of $\mathcal{K}$.*

The proof follows straight from the linearity of $\pi_i(\kappa(v), v)$ and the constraints (2.1) and (2.4). One implication of this lemma is that not all contracts will typically be IC and BIR.

Finally, the *ex-ante* individual rationality conditions that allow voluntary investment I_i and participation at the $t = 0$ will hold — as long as the gains from the contractual relationship are non-zero and there are no dead-weight losses. For non-triviality, the latter condition will be assumed throughout.

2.2 Efficient Securities

Following Holmström and Myerson (1983), three efficiency criteria can be defined in this context, depending on *when* the welfare of the two agents is evaluated. Accordingly, a contract that maximizes the total welfare is *ex-ante* efficient (κ_E^*) if the welfare is computed before the agents receive their private information, *interim* efficient (κ_I^*) if the agents know only their own private information, and *ex-post* efficient (κ_P^*) if all information is common knowledge. Correspondingly, the utilities of the agents at each stage is given by,

$$\Pi_i[\kappa] = E[\pi_i(\kappa(v), v)] \qquad (\textit{ex-ante}) \tag{2.6}$$

$$\Pi_i[\kappa | v_i] = E_{-i}[\pi_i(\kappa(v), v)] \qquad (\textit{interim}) \tag{2.7}$$

$$\Pi_i[\kappa | v] = \pi_i(\kappa(v), v) \qquad (\textit{ex-post}). \tag{2.8}$$

Define $\lambda_i^\ell(v) : V \mapsto \mathcal{R}_+$ and a social welfare function $W^\ell(\kappa)$ where

$$W^\ell(\kappa) \equiv \sum_{i=1}^{2} E[\lambda_i^\ell(v)\pi(\kappa(v), v)]. \tag{2.9}$$

[27]Note that $\mathcal{K}^*$ differs from Δ^* of Holmström and Myerson (1983) in that it includes BIR constraints as well.

Then, an efficient contract κ_ℓ^* for all $\ell \in \{E, I, P\}$ is given by[28]

$$\mathbf{P2}(\ell): \quad \kappa_\ell^* \quad \in \quad \underset{\{\kappa \in \mathcal{K}^*\}}{\operatorname{argmax}} \quad W^\ell(\kappa)$$
$$s.t. \quad \text{Condition (2.3).}$$

That is, κ_ℓ^* maximizes the welfare function in (2.9) subject to IC and BIR constraints, as well as the ex post settlement constraint (2.3). The three types of efficient contracts can be obtained as solutions to this programming problem, by imposing three types of measurability restrictions on $\lambda_i^\ell(v)$. An *ex-ante* efficient contract κ_E^* is obtained if $\lambda_i^E(v)$ are constants independent of v, an *interim* efficient contract κ_I^* is obtained if $\lambda_i^I(v)$ is measurable with respect to only v_i, and an *ex-post* efficient contract κ_P^* is obtained if $\lambda_i^P(v)$ is measurable with respect to v.

Let $\mathcal{K}_E^*$, $\mathcal{K}_I^*$, $\mathcal{K}_P^*$ be the set of all *ex-ante, interim, ex-post* efficient contracts. We are now ready prove the following.

THEOREM 2.2. *The ex-ante and interim efficient contracts, $\kappa_\ell^* \in \mathcal{K}_\ell^*$ for $\ell \in \{E, I\}$, offer agent j the entire wealth and agent i nothing in the event of a unilateral disagreement, iff*

$$\mathcal{K}_P^* = \phi, \quad L > 0 \quad \textit{and}$$
$$\sup_{\{v_i \in V_i^*(\kappa_\ell)\}} E_{-i}[1_{\{v \in V^*(\kappa_\ell)\}}] \quad > \quad \sup_{\{v_j \in V_j^*(\kappa_\ell)\}} E_{-j}[1_{\{v \in V^*(\kappa_\ell)\}}] \quad \forall \ell \in \{E, I\}. \tag{2.10}$$

This result can be understood as follows. First note that both *ex-ante* and *interim* welfare can be improved by reducing the threat points of the contracting game. If *ex-post* efficient contracts do exist, then the contract game will not end in a disagreement. On the other hand, when the set of *ex-post* efficient contracts is empty, disagreement becomes a possibility, and the status quo utilities (threat points) become important for welfare. In particular, since threat points themselves are endogenously determined by the choice of the security, we can lower the threat points by decreasing the agents' status quo utilities. However, the *ex-post* settlement constraint (2.3) then becomes binding, and the payoffs to both agents have to add

[28] Note that the objective function includes any gross returns from the investment I as a result of an agreement.

upto the liquidation value L. Note that, neither the ex ante nor the interim efficient design involves simply balancing out the agents' threat points evenly. If the agents are *asymmetrical*, in the sense that the subjective probability of a unilateral disagreement for agent i (conditional on her private information) is greater than that of j (condition (2.10)), then it is possible to lower the threat point and improve efficiency by giving agent i nothing and agent j all of L in the event of a disagreement.[29] As in the last section, the interpretation is that agent j is more *disagreeable* than agent i in equilibrium, and hence receives all the liquidation value in the event of a unilateral disagreement. Of course, this is more subtle than it appears, since the degree of disagreeability is determined endogenously in equilibrium by the choice of ex ante (or interim) efficient contract. In contrast, if the agents are symmetric, then security design becomes irrelevant for welfare, and hence any security allocation in the event of a disagreement will do just as well.

It is important to note that the agents must be *asymmetrically disagreeable*, i.e., having different subjective conditional probabilities of unilateral disagreement, for Theorem 2.2 to hold. Other, more superficial, differences between agents may not suffice. For instance, in a bilateral trading problem, one agent being a seller and the other being a buyer may not satisfy (2.10), since a seller's problem is isomorphic to a buyer's problem. Moreover, shifting of the support of the valuations for one agent may not suffice either. Generally speaking, more structure needs to be imposed on the contracting game before one can describe what constitutes "sufficient asymmetry" in the threat points. For example, in the joint venture application of Section 1, asymmetry in the threat points was induced by the differences in the distribution of private benefits to the firms.

2.3. Efficient Security Design and Capital Intensity

Suppose the initial investment is not very capital intensive, in the sense that it is small relative to the potential gains from the contractual relationship. There are two effects. On one hand, from (2.3) and (2.4) it follows that the BIR constraints will be less relaxed, and hence the threat points themselves will be less relevant for welfare. On the other hand, the feasible

[29] Of course, if agent i does not receive any liquidation value in the event of a disagreement, his optimal initial investment I_i will be correspondingly reduced, and the other agent's initial investment correspondingly increased.

set $\mathcal{K}^*$ will be smaller, thus reducing overall welfare — since the initial capital helps to improve efficiency in the agreement region. In the extreme case of no investment, $L = 0$, and the choice of the threat points becomes completely irrelevant. Thus, the choice of the security structure serves no useful incentive role in this case. In particular, simple partnership-style shares to both agents in the disagreement region will do just as well. On the other hand, if the investment is highly capital intensive $L >> 0$, a threat point with the debt-like security structure described in Theorem 2.2 *strictly* improves welfare. This discussion can be summarized as follows.

COROLLARY 2.3. *The ex-ante and interim efficient contracts will involve a debt-like feature if the initial investment is capital intensive. In the case of small or no capital investment, there is no particular welfare advantage from a debt-like structure: a simple partnership-style share security in the disagreement region will suffice.*

The case of little or no capital investment corresponds to professional service industries such as auditing, consulting, law and investment banking, where much of the value of the firms' assets derives from human capital. Thus, Corollary 2.3 offers an explanation for why partnership structure, and not quasi-debt and residual claim structure, has historically been prevalent in these service industries: The threat point for further contracting is nearly zero due to the absence of capital investment, and hence quasi-debt serves no incentive purpose in these industries. As these service firms diversify into other areas of business requiring more capital investment — such as informations systems consulting in the case of accounting firms and merchant banking and large-scale trading in the case of investment banks — the capital intensity increases. This, in turn, raises the threat points for further contracting, and hence these firms can be expected to prefer quasi-debt in their capital structure. This explanation is, in fact, consistent with the diversification experience of firms in these service industries in the last decade.[30]

2.4 Contracting through an Intermediary

As mentioned earlier, if the two informed agents are symmetrical, in the sense that they are equally likely to cause a unilateral disagreement, i.e., $\sup_{\{v_i \in V_i^*(\kappa_\ell)\}} E_{-i}[1_{\{v \in V^*(\kappa_\ell)\}}] = \sup_{\{v_j \in V_j^*(\kappa_\ell)\}} E_{-j}[1_{\{v \in V^*(\kappa_\ell)\}}]$, then the threat points become irrelevant for welfare. But whether

[30]Of course, there may be other advantages to quasi-debt and partnership structures, such as tax benefits, that are ignored in this analysis.

the agents' threat points are symmetrical or asymmetrical, both *ex-ante* and *interim* efficiency can be improved by bringing in an uninformed third agent as an intermediary into the contract negotiations. To see this, consider the simple case of an intermediary who has no private information and has no productive role, but makes an initial investment of $I \geq I_3 \geq 0$, and breaks-even on average.[31] We denote $\hat{\kappa}$ as a contract in the three-agent game that specifies the payoffs and decisions explicitly only for the two informed agents. We will specify the payoffs to the uninformed intermediary indirectly, as implied by the contract $\hat{\kappa}$.[32] The break-even condition for the intermediary is

$$\Pi_3[\hat{\kappa}] \equiv E[\pi_3(\hat{\kappa}(v), v)] \quad = \quad I_3. \tag{2.11}$$

For instance, in an application involving debt/equity issues, the intermediary could be an uninformed investor or an underwriter of the issue. In the case of a contest for corporate control, the intermediary could be a passive, neutral investor or a bank providing bridge financing. In a trading exchange that charges trading fees, she could be interpreted as a specialist or a market maker.

Modifying the earlier model of two agents, note that the *ex-post* settlement constraints are now different: the status quo payoffs to the informed agents no longer need to add upto L, since the uninformed agent could be paid the liquidation value in the event of a unilateral disagreement. Condition (2.3) becomes

$$\sum_{i=1}^{2} \pi_i(\kappa(v), v) \quad = \quad 0, \quad \forall v \in V^*(\kappa). \tag{2.12}$$

[31]More generally, this intermediary may have private information and may even have a productive role as well. Surprisingly, in the case where he is informed, it can be shown that the efficiency levels will be greater than that with just two informed agents. The reason is that having three informed agents allows more flexibility in designing the threat points of all agents. For instance, if two agents make "bad" reports, the residual wealth can be allocated to the third agent who has a positive probability of making a "good" report. In the extreme, if the intermediary is completely uninformed (as she is here), the overall welfare will be strictly better than if she were informed.

[32]The reason for such a specification is that the dimension of the contract space for three agents will otherwise be larger than the dimension in the previous case with two agents. Specifying the intermediary's payoffs indirectly, (as implied by the contract $\hat{\kappa}$) preserves the same dimensionality of the contract space and allows for valid comparisons with the two-agent case.

Denote the set of IC and BIR contracts for the informed agents as $\hat{\mathcal{K}}^*$. The three types of efficient contracts, $\hat{\kappa}_\ell$ for $\ell \in \{E, I, P\}$, are given by

$$\mathbf{P3}(\ell): \qquad \hat{\kappa}_\ell^* \in \operatorname*{argmax}_{\{\hat{\kappa} \in \hat{\mathcal{K}}^*\}} W^\ell(\hat{\kappa}) \quad s.t. \quad \text{Condition (2.12)}, \tag{2.13}$$

where the usual measurability restrictions on $\lambda_i^\ell(v)$ apply for the three types of efficient contracts. Let $\hat{\mathcal{K}}_\ell^*$ for $\ell \in \{E, I, P\}$ be the set of all *ex-ante, interim and ex-post* efficient contracts.

PROPOSITION 2.4. *The ex-ante and interim efficient contracts among the three agents, $\hat{\kappa}_\ell^* \in \hat{\mathcal{K}}_\ell^*$ for $\ell \in \{E, I\}$, will involve a residual claim for both the informed agents, while the uninformed intermediary will receive the entire wealth in the event of a unilateral disagreement, iff*

$$\mathcal{K}_P^* = \phi, \quad L > 0. \tag{2.14}$$

For sufficiently large L, $\hat{\mathcal{K}}_P^* \neq \phi$. Moreover, the total welfare at the ex-ante and interim stages when contracting through an intermediary strictly dominates that when contracting directly.

As before, condition (2.14) merely requires that disagreements be possible and that threat points be welfare-relevant. Note that the design of security in the presence of interemdiary does not depend on whether the two informed agents are symmetrical or not. In particular, even if they are asymmetrical and Theorem 2.2 applies, efficiency can be further improved by offering *both* the informed agents residual claims. This is because both their threat points can be reduced to *zero* by offering the uninformed intermediary L in the event of a unilateral disagreement. Such a contract strictly dominates the contract in Theorem 2.2 that offers one of the informed agents all of the liquidation value.

Interestingly, the improvement in welfare when contracting among three agents versus two agents does not arise from the usual increased insurance opportunities, as all agents are risk-neutral here. Rather, it comes from a reduction in threat points with the increased number of agents. In fact, if the uninformed agent makes a sufficiently large investment relative to the liquidation value, then we obtain the standard debt contract.

COROLLARY 2.5. *If $I_3 \geq L > 0$, then the ex-ante and interim efficient contracts may involve a standard debt claim for the uninformed agent:*

$$\pi_3(\hat{\kappa}(v), v) = \begin{cases} L & \text{if} \quad v \in V^*(\kappa) \\ D & \text{else,} \end{cases} \tag{2.15}$$

where D is chosen to satisfy (2.11).[33]

That is, the third agent receives a fixed payment D, which can be interpreted as the face value of the debt claim in the event of a good outcome, and the liquidation value L when the outcome is bad. Note that while the third agent's payoff in the bad states L is unique, his payoff in the good states is not. In particular, securities resembling quasi-equity, eg. with convertible options, are possible in the good states. These features are likely to arise if the role of the third agent is expanded to include monitoring or other productive activities.

3. CONCLUSION

This paper has presented a theory of efficient security design, by explicitly taking into account the dynamic role of threat points that may affect overall contracting efficiency. A key insight is that careful security design can promote overall contracting efficiency, and this task boils down to the efficient design of threat points. Contrary to what may be expected, this can not be achieved by evenly balancing the threat points of agents. Rather, we must penalize the agent with the greatest threat point, who interestingly is not the most disagreeable agent. It was shown that efficient security design implies a quasi-debt/residual claim structure in a large family of contracting games that involve investments and asymmetric information. In particular, under weak conditions, all the *ex-ante* and *interim* efficient designs will involve residual claim for all parties but the most disagreeable one, which will receive a debt-like claim. In an application involving a joint venture between two firms, it was shown that all *ex ante* efficient contracts will allocate a debt-like claim for the most disagreeable venture partner, awarding residual claims for the less disagreeable one.

[33] Since the uninformed agent is paid D in the event of an agreement, the payoffs to the informed agents will be reduced by this amount in this event. But this has no incentive effects since D is a constant.

The results are also robust to risk-aversion. To see this, note that the model with risk-averse agents will closely follow the risk-neutrality model of Section 2. The only difference is that pure contracts will be defined over utilities (instead of wealth), and the actual contract will be defined as a probability mixture of pure contracts — thus preserving the technical properties of the set $\mathcal{K}^*$. Since quasi-debt/residual claim structure is a corner solution, it may seem at first glance that it may not be efficient under risk-aversion. This is not true, however, since the corner solution helps reduce threat points of the agents, by preventing risk-sharing in the event of a disagreement. In fact, Theorem 2.2 holds independent of asymmetry. Moreover, an uninformed intermediary will, in addition to reducing the threat points of the informed agents, will also offer insurance. Thus, quasi-debt will still be *ex-ante* and *interim* efficient under risk-aversion. Finally, the insights can also be extended to moral hazard (hidden action) problems, since once the action is chosen, the incentive constraints are typically isomorphic to the adverse selection counterparts.

It may be argued that since threat points are the source of the problem, perhaps threatening to get rid of the liquidation value, i.e., by "burning money," in the event of a unilateral disagreement will force the agents to agree without loss of efficiency.[34] This is not optimal here, however, for two reasons. First of all, agents will correspondingly reduce their ex ante investments if they expect such a burning of money to occur in equilibrium. Second, contracting through an intermediary strictly dominates disposing off the assets, since dead-weight losses can be eliminated. Any money to be burnt can now be paid to the intermediary, who, because of the break-even constraint, will supply more funds in the agreement states. Thus the intermediary subsidizes marginal agreements that could not have been reached otherwise, and helps increase efficiency. If the liquidation value is large enough, first-best can be achieved because the intermediary will now be willing to offer more to reach an agreement.

Our results are consistent with the historically observed partnership structure in industries such as auditing, consulting, law and investment banking which involve little capital

[34]There are games in which one player can force an equilibrium of her choice by unilaterally threatening to burn her own payoffs (Fudenberg and Tirole (1992)). But this requires iterated elimination of dominated strategies, a somewhat different equilibrium concept from the Bayesian-Nash equilibrium concept used here. In any case, it is not clear how this would work in our model, since both the agents here must agree to any burning of the residual wealth in the event of a disagreement.

investment, and with the prevalence of debt-like structures in more capital intensive industries such as manufacturing. As these service firms have been diversifying into capital intensive businesses recently, they have shifted toward debt and quasi-debt financial structures, as predicted by our theory.

The model in this paper can be extended to include a series of nested contracting games, where the threat point of agents in one game will be determined by the outcome of another game, whose threat point will be determined by yet another game and so on, possibly involving many different agents. Ex ante and interim efficient securities in such a formulation will turn out to be a series of debt-like claims with a *priority* order, resembling various degrees of senior and subordinated debt.

While quasi-debt securities may be *ex-ante* and *interim* efficient, they may not be renegotiation-proof, in the sense of Maskin and Tirole (1992). When only one party has private information, however, Holmström and Myerson (1983) have shown that *interim* efficient contracts will also be durable and renegotiation-proof. With bilateral asymmetric information, while not all debt-like securities will be renegotiation-proof, an important question is whether there exists *any* debt-like claim that is. Insights from the recent literature on renegotiation under asymmetric information,[35] suggests that with sufficient residual private information, debt-like securities may sometimes be renegotiation-proof. This will be an important topic for future research.

[35] See, for instance, Giammarino (1989), Fulghieri and Nagarajan (1992) and Maskin and Tirole (1992).

APPENDIX

Proof of Lemma 1.1 The IC condition (1.4) can be rewritten as

$$\Pi_i(b_i) \geq \Pi_i(\hat{b}_i) + (b_i - \hat{b}_i)P_i(\hat{b}_i) \quad \forall i \quad \text{and} \quad b_i, \hat{b}_i \in [\underline{b}_i, \bar{b}_i] \tag{A1}$$

On the other hand, to induce a firm of type $\hat{b}_i$ to report the truth and not b_i, the IC contract must satisfy

$$\Pi_i(\hat{b}_i) \geq \Pi_i(b_i) - (b_i - \hat{b}_i)P_i(b_i) \quad \forall i \quad \text{and} \quad b_i, \hat{b}_i \in [\underline{b}_i, \bar{b}_i]. \tag{A2}$$

Combining (A1) and (A2)

$$(b_i - \hat{b}_i)P_i(b_i) \geq \Pi_i(b_i) - \Pi_i(\hat{b}_i) \geq (b_i - \hat{b}_i)P_i(\hat{b}_i) \quad \forall i \quad \text{and} \quad b_i, \hat{b}_i \in [\underline{b}_i, \bar{b}_i]. \tag{A3}$$

Taking limits as $\hat{b}_i \to b_i$, we get $\Pi_i'[b_i] = P_i(b_i)$ *a.e.* Integrating

$$\Pi_i(b_i) = \Pi_i(b_i^*) + \int_{b_i^*}^{b_i} P_i(\hat{b}_i)d\hat{b}_i,$$

and rewriting yields (1.5), where b_i^* represents the type with the lowest expected payoff. ∎

Proof of Lemma 1.2: The only-if part. The cumulative expected payoff to both firms at $t = 2$ is,

$$\begin{aligned}
E&\left\{[y_2 + b_1 + b_2 - c]p(b_i, b_j)\right\} + I + y_1 \\
&= \sum_{i=1}^{2} E\{\Pi_i(b_i)\} \\
&= \sum_{i=1}^{2} \Pi_i(b_i^*) + \sum_{i=1}^{2} E_{b_i}\left\{E_{\hat{b}_i}\left\{\frac{P_i(\hat{b}_i)}{g_i(\hat{b}_i)} 1_{\{b_i^* \leq \hat{b}_i \leq b_i\}}\right\}\right\} \text{(since } \kappa \text{ is IC)} \\
&= \sum_{i=1}^{2} \Pi_i(b_i^*) + \sum_{i=1}^{2} E_{b_i}\left\{\frac{[1 - G_i(b_i)]}{g_i(b_i)} P_i(b_i)\right\} \text{(by changing the order of expectations)} \\
&= \sum_{i=1}^{2} \Pi_i(b_i^*) + \sum_{i=1}^{2} E\left\{\frac{[1 - G_i(b_i)]}{g_i(b_i)} p(b_i, b_j)\right\} \text{(by definition, from (1.2)).}
\end{aligned} \tag{A4}$$

The expectations are taken over the restricted domain $[b_i^*, \bar{b}_i]$. Rearranging the left hand side and the right hand side of (A4) and imposing the BIR constraints yields (1.9).

To prove the if part of the proposition, let $P_i(b_i)$ be non-decreasing and let (1.9) hold. Consider the transfer payment rule such that $\kappa \in \mathcal{K}^*$, as follows.

$$x_i(b_i, b_j) = \text{const}_i + \int_{b_i^*}^{b_i} \hat{b}_i dP_i(\hat{b}_i). \tag{A5}$$

It is straight forward to verify that this contract is IC and BIR using standard techniques (see Myerson and Satterthwaite (1983)) and we omit this step here. ∎

Proof of Proposition 1.3: For an ex post efficient contract, $b_i^* = \underline{b}_i$. Plugging this and the condition that $p(b_i, b_j) = 1$, iff $y_2 + b_1 + b_2 \geq c$ into equation (1.9), we get the result. ∎

Proof of Proposition 1.5: The Lagrangean for program **P1** is, ignoring the constants,

$$\max_{\kappa} \quad \mathcal{L}(\kappa) = E\left\{\left[(1+\mu)[y_2 + b_1 + b_2 - c] - \sum_{i=1}^{2} \mu \frac{[1 - G_i(b_i)]}{g_i(b_i)}\right] p(b_i, b_j)\right\} - \mu \sum_{i=1}^{2} \bar{s}_i L G_j[b_j^*(\kappa)]. \tag{A6}$$

where μ is the Lagrange multiplier for the constraint in **P1**. Define $\alpha = \dfrac{\mu}{1+\mu}$. The program (A6) becomes,

$$\max_{\kappa} \quad \mathcal{L}(\kappa) = \sum_{i=1}^{2} E\left\{\left[y_2 + b_1 + b_2 - c - \alpha \frac{[1 - G_i(b_i)]}{g_i(b_i)}\right] p(b_i, b_j)\right\} - \alpha \sum_{i=1}^{2} \bar{s}_i L G_j[b_j^*(\kappa)]. \tag{A7}$$

Pointwise optimization gives the solution $p^*(b_i, b_j)$ as in (1.11).

Now suppose κ^* is *ex-ante* efficient, and $\bar{s}_i^* > 0$ when $G_i[b_i^*(\kappa)] < G_j[b_j^*(\kappa)]$ — contrary to (1.11). Then by setting $\bar{s}_i^* = 0$, the maximand (A6) can be increased, and the resulting contract is strictly better than κ^*, a contradiction. ∎

Proof of Theorem 2.2: First, we prove the if-part by contradiction. If $\mathcal{K}_P^* = \phi$, then $V^*(\kappa)$ is non-empty. The status quo utility for i is $\sup_{\{v_i \in V_i^*(\kappa)\}} E_{-i}[\pi_i(\kappa(v), v) 1_{\{v \in V^*(\kappa)\}}]$ for $L > 0$. Assume that κ_E^* and κ_I^* are solutions to program **P2**(E) and **P2**(I) respectively, and $\sup_{\{v_i \in V_i^*(\kappa)\}} E_{-i}[1_{\{v \in V^*(\kappa)\}}] > \sup_{\{v_j \in V_j^*(\kappa)\}} E_{-j}[1_{\{v \in V^*(\kappa)\}}]$. Let $\pi_i^*(\kappa(v), v) > 0$ and $\pi_j^*(\kappa(v), v) < L$ contrary to the statement in the Theorem. Then, given linearity, the constraint

(2.4) can be relaxed by setting $\pi_i^*(\kappa(v), v) = 0$ and $\pi_j^*(\kappa(v), v) = L$, for all $v \in V^*(\kappa)$. This contradicts the presumption that κ_E^* and κ_I^* are efficient in the first place. This proves the if-part.

If $\mathcal{K}_P^*$ is not empty, then $V^*(\kappa) = \phi$ and the status quo expected payoffs are zero. The same is true if $L = 0$. Furthermore, if $\sup_{\{v_i \in V_i^*(\kappa)\}} E_{-i}[1_{\{v \in V^*(\kappa)\}}] = \sup_{\{v_j \in V_j^*(\kappa)\}} E_{-j}[1_{\{v \in V^*(\kappa)\}}]$, then again the status quo contract becomes irrelevant for welfare. Thus, the only-if part follows. ▮

Proof of Proposition 2.4 This proof closely follows that of Theorem 2.2, and hence only an outline will be offered here. First consider, without loss of generality, the following contract for agent 3.

$$\pi_3(\hat{\kappa}(v), v) = \begin{cases} L & \text{if} \quad v \in V^*(\kappa) \\ D & \text{else} \end{cases} \tag{A8}$$

for some D. Thus, $\pi_i(\hat{\kappa}(v), v) = 0$ for all $i \in \{1,2\}$ and $v \in V^*(\hat{\kappa})$. Hence, the BIR condition (2.4) becomes

$$E_{-i}[\pi_i(\kappa(v), v)] \quad \geq \quad 0, \quad \forall v \in V \quad \text{and} \quad i = \{1,2\}. \tag{A9}$$

Note that (A9) is more relaxed when compared to (2.4). Hence, $\hat{\mathcal{K}}^* \supset \mathcal{K}^*$ and the results follow. ▮

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